DOCUMENT RESUME

ED 223 246 IR 010 515

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TITLE Effects of Spatial Configuration on Search of Visual Displays. Umea Psychological Reports No. 151.
INSTITUTION Umea Univ. (Sweden).
SPONS AGENCY Swedish Council for Social Science Research, Stockholm.
PUB DATE 80
NOTE 20p.; For related documents, see IR 010 516-518.
PUB TYPE Reports - Research/Technical (143)

EDRS PRICE MF01/PC01 Plus Postage.
DESCRIPTORS *Cognitive Processes; College Students; Eye Movements; *Patterned Responses; Psychological Studies; *Serial Ordering; Spatial Ability; *Visual Perception; *Visual Stimuli
IDENTIFIERS Pattern Organization; Scanning; *Selective Attention; Stimulus Characteristics

ABSTRACT

The visual scanning of redundant and random spatial configurations of two-digit numbers was investigated in a target recognition task. The experimental technique involved a brief exposure of a probe (a two-digit number) at the center of the visual field, followed by a spatial pattern of 16 two-digit numbers which included the matching target in half the number of trials. The experiment was run and controlled by a PDP 8/e computer, and five different display types, varying in spatial order of elements, boundaries of the stimulus field, and grouping of the elements, were presented on an alpha-numeric display. The correlation between the spatial and numerical orders of the stimulus elements was either perfect or zero. An ordered scanning occurred for systematic spatial configurations, while for the random configurations, recognition seemed to be based on the perceived clarity of elements. Performance was facilitated when the spatial and numerical orders of the elements were related, but was detrimental when they were unrelated. For random spatial configurations, the recognition of the target was dependent on its distance to the point of fixation and independent of the numerical relations. The general effects were more pronounced when the subjects were informed about the relation between spatial and numerical order. Data tables and 15 references are included in this report. (Author/LMM)

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EFFECTS OF SPATIAL CONFIGURATION ON SEARCH OF VISUAL DISPLAYS

by

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UMEA PSYCHOLOGICAL REPORTS

No. 151 1980

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IR010515

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EFFECTS OF SPATIAL CONFIGURATION ON SEARCH OF VISUAL DISPLAYS

Brännström, L. Effects of spatial configuration on search of visual displays. Umeå Psychological Reports, No. 151, 1980 - The visual scanning of redundant and random spatial configurations of two-digit numbers was investigated in a target recognition task. The correlation between the spatial and numerical orders of the stimulus elements was either perfect or zero. An ordered scanning occurred for systematic spatial configurations while for the random configurations recognition seemed to be based on the perceived clarity of elements. Performance was facilitated when the spatial and numerical orders of the elements were related but was detrimental when they were unrelated. For random spatial configurations the recognition of the target was dependent on its distance to the point of fixation and independent of the numerical relations. The general effects were more pronounced when the subjects were informed about the relation between spatial and numerical order.

The decision where to direct visual attention usually rests to a large extent on the processing of incoming visual information. The fact that the essential processing of sensory information occurs during the fixation phase (Loftus & Mackworth, 1978), and that there is a substantial correlation between post-fixation tendencies and the spatial positions scanned during a single fixation (Crovitz & Daves, 1962), point to the importance of the information processes preceeding actual eye movements. The effectiveness of search, whether it be during a single eye fixation or as a sequence of several fixations, should be closely tied to the spatial configuration of elements to be processed.

The spatial configuration of visual elements can vary from being systematic (e.g. forming rows and columns), to being random where element positions are non-redundant. The importance of the dimension redundancy-randomness when judging spatial patterns has been demonstrated by Glushko (1975). He found a close relation between redundancy and preference judgments of pattern goodness (see also Garner, 1974).

Pattern goodness also has positive effects on information processing tasks (e.g. Bell & Handel, 1976; Checkosky & Whitlock, 1973; Clement, 1964; Clement & Varnadoe, 1967; Garner & Sutliff, 1974). Related concepts to pattern goodness are "good figure" (i.e. Gestalt; Koffka, 1935) and perceptual uncertainty (Attneave, 1954). However, although pattern goodness positively affects performance in information processing tasks, little is still known about why it does have that effects. There is a need for emphasizing configurational aspects of visual stimuli on information processing more than has been done to date. This is well summarized by Estes (1978): "A topic that has been much more conspicuously represented in general expository literature than in specific research reports is that of global principles of form and grouping" (p. 214). The present experiment is an attempt to evaluate the effects of spatial configurations on the scanning of multi-element displays.

One interesting question is how spatial configuration affects the choice of scanning strategy. A decision must be made very early in the processing of visual information. If the spatial configuration is systematic the probability of an ordered search should be high. It is a well-known fact that a left-to-right scanning occurs for letter materials ordered in rows. This has been explained by reference to well-learned reading habits (e.g. Heron, 1957; Mewhort, Merikle & Bryden, 1969). As soon as the spatial configuration becomes less systematic other scanning orders should become more prevalent. If the elements form a random spatial pattern, then an ordered scan should probably not occur. Instead, the clarity or informational richness of the elements should form the basis for the search, where the main physical determinants are the distance of the target from the fixation point and the degree of lateral interference between elements.

Brännström (1980) has shown that magnitude estimations of content attributes are affected by the spatial configuration of the elements to be judged. Therefore, another question is whether the spatial configuration and the informational content of elements interact in an operational test situation. By using two-digit numbers as displays elements it was possible to vary the relationship between the spatial and the numerical orders of elements. A systematic spatial order might raise the subject's expectations of a numerical order of elements, in which case scanning should be affected accordingly. A random spatial configuration should make subjects less likely to expect such a numerical order. In that case scanning should rather be based on the clarity of elements. Thus, in one condition spatial and numerical order were perfectly correlated, in another the two orders were independent.

Another prediction was made that the subject's knowledge about the relationship between spatial and numerical order should affect his scanning behavior. Scanning behavior should become more consistent when subjects are informed as compared to when they are uninformed. When informed, a reasonable scanning strategy should be one where the subject persistently tries to utilize numerical order. That strategy should be efficient only when spatial and numerical orders are correlated but inefficient otherwise.

Method

The experimental technique used in the present experiment involved a brief exposure of a probe (a two-digit number) at the center of the visual field. Shortly thereafter a spatial pattern of sixteen two-digit numbers was exposed which included the matching target in half the number of trials. The exposures of the probe and the stimulus display were brief so as to minimize excessive eye movements during stimulus presentation.

Stimulus material

A stimulus display consisted of sixteen two-digit numbers randomly drawn without replacement from the total set of two-digit numbers but with the exclusion of numbers ending on zero or those containing identical pairs of digits. Thus, the remaining set consisted of seventy-two two-digit numbers. For each trial the numbers used in a display pattern were drawn at random.

Five different display types were used. The displays were constructed by varying the following dimensions: Systematic vs. random spatial order of elements, regular vs. irregular boundaries of the stimulus field, and spatially grouped vs. ungrouped positions of the elements. Display type I consisted of a homogenous and systematic pattern of numbers (Figure 1 a). Display type II was systematic but with a grouping (Figure 1 b). Display type III differed from type II only with respect to one single position (Figure 1 c). For display type IV the boundaries were regular while the four inner positions were randomly located (Figure 1 d). Finally, type V had a random distribution of number positions (Figure 1 e). Thus the five displays types represented different degrees of spatial order, from systematic (I) to random order (V).

Figure 1 a-e. Display types.

The minimum distance between the borders of a pair of two-digit numbers was .37°, horisontally, and .54°, vertically. Each two-digit number occupied at most a width of .48° and a height of .27°. A total of 140 (7 rows x 20 columns) positions existed with the probe position on the fourth row and the tenth and eleventh columns. This resulted at most in a total display width of 5.17° between the extreme positions and a total height of 2.27°.

For display types III-V eight different stimulus displays were constructed of each in order to make it difficult for the subject to remember the specific spatial configurations and, instead, force them to rely on the immediate visual impression of the displays.

For each display type 16 different positions were used as target positions. Thus, for type I-III the target number appeared once on each number position. For type IV only the four middle number positions were determined randomly while the positions on the field boundaries were targets once. Finally, for type V sixteen randomly selected target positions were used with the restriction that they should be distributed evenly across the display.

The correlation between numerical size and spatial position could be perfect or zero (systematic versus random numerical order). Perfect correlation means that the numbers were arranged in increasing numerical size, from left to right and always beginning with the first row. The sample of numbers was randomly determined for each trial.

With five display types, sixteen target positions, two numerical orders and the target present or absent there were 320 stimulus displays which were selected completely at random within a block of trials.

Procedure

The experiment was run and controlled by a PDP 8/e computer and the different display types were presented on an alfa-numeric display (Burrough's self-scan panel display).

The subject was sitting in front of the panel display at a distance of 150 cm in a shielded room. The following sequence of events was presented on each trial: The probe number appeared in the center of the computer display for 40 msec followed by a dark interval of 200 msec after which a stimulus configuration was exposed for 500 msec. The exposure time permitted a maximum of one eye-movement but subjects mostly fixated the center position of the display during the whole stimulus exposure. (Cf. Mackworth, 1976, who found evidence for a lengthened fixation time with increased visual load). All 320 trials were given in one sequence with each trial interrupted by a 4.26 sec long pause before the next trial. The subject was forewarned by a brief tone, .5 sec before the probe onset, to fixate the faint fixation point just below the probe position. The digits were orange-red against a dark background. The following luminance levels were used: General background illumination = .8 mL, display background = .2 mL and stimulus digits 1.7 mL. The luminance value of digits was estimated from the average luminance values of the digits 1-9.

The subject's task was to identify the probe number and, at the time of the display exposure, indicate by pressing one of the two buttons whether the target number was present or not. The button for yes-answers was attached to one arm of the chair, the button for the no-answers to the other arm. Button positions were counter-balanced across subjects. Feedback on the frequency of yes- and no-responses was given after each block of 320 trials in order to minimize response bias. The subjects were also told that the target could occupy any position on the display, and that the best strategy should be to fixate the center of the visual field.

The experiment consisted of one practice block and six experimental blocks distributed over seven different days. In the practice block the numerical order was random. The practice block consisted of 160 trials.

The four female and three male university students who served as paid subjects in the first session were not informed about the relationship between spatial and numerical order (the uninformed group). After about one month four of them (three females and one male) participated in an additional session of three experimental blocks where they were informed about the possible correlation between the spatial and numerical orders (the informed group). Thus they were told that numerical and spatial order were unrelated for half of the trials but perfectly related for the other half. The conditions occured in random order.

Each experimental block lasted about one hour and the subjects were paid 15 Skr (about 4 dollars). All subjects were right-handed and had normal vision.

Results

The mean proportion of correct (yes and no) responses was similar when the subjects were uninformed ($\bar{p} = .63$) and informed ($\bar{p} = .65$) about numerical order. A bias towards answering "no" ($\bar{p} = .55$) more often than "yes" ($\bar{p} = .45$) was noted. The criterion used by the subjects seems to reflect a general cautiousness.

Systematic numerical order was beneficial to search performance as compared to random numerical order ($\bar{p} = .663$ vs. $.603$), suggesting that subjects used the numerical size of the probe number as a cue in the scanning. The effect of numerical order was more pronounced in the informed group of subjects. The difference between systematic and random numerical order was $\bar{p} = .088$ as compared to a difference of .032 in the uninformed group. The main effect of numerical order was statistically significant in both information conditions ($F(1,6) = 10.624$, $p < .05$ in the uninformed group and $F(1,3) = 18.216$, $p < .05$ in the informed group). The interaction effect between information condition and numerical order is shown in Figure 2, and is statistically significant at the 10 per cent level with an $F(1,3) = 7.197$.

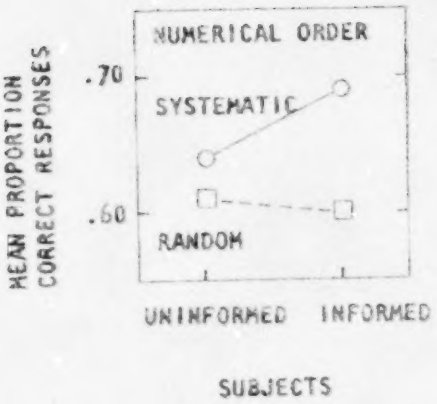

Figure 2. The interaction between the information condition and numerical order. Data are from the subjects participating in both the uninformed and informed groups (N=4).

These results taken together suggest that the subjects utilize the numerical size of the probe as a cue in scanning. The use of this cue is apparently conditioned to the spatial configuration of numbers; there is an interaction effect between display type and numerical order both in the uninformed and the informed conditions. Figure 3 shows the interaction effect for both information conditions.

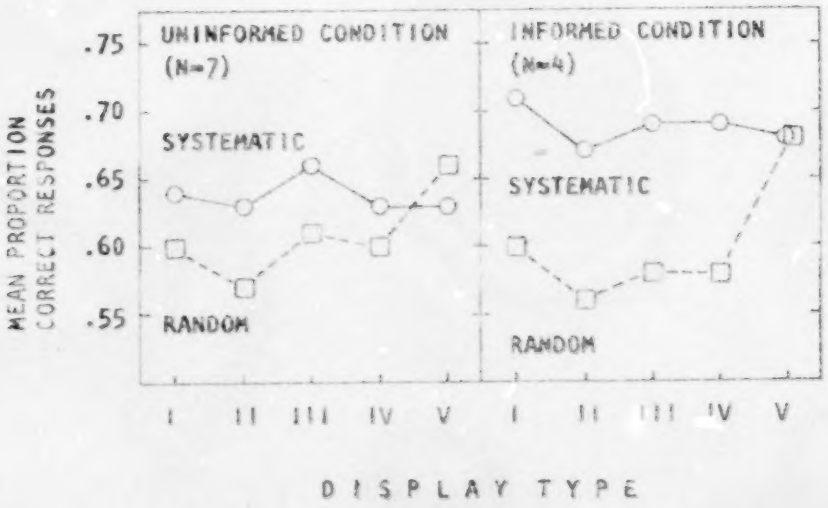

Figure 3. The interaction of display type and numerical order in the uninformed condition (left panel) and the informed condition (right panel).

Both interactions were statistically significant with an $F(4,24) = 2.931$; $p < .05$ in the uninformed condition and with an $F(4,12) = 3.573$; $p < .05$ in the informed condition. (The interaction effect in the uninformed condition is similar with both N=4 and N=7, thus, the same effect is obtained in the group of subjects participating in both the uninformed and informed groups as in the total group). Therefore, when the numerical order is systematic the cue facilitates performance for display types I-IV. When the numerical order is random the cue is inadequate, a fact revealed by its detrimental effects on the more systematic display types. This difference in performance between numerical orders is further increased when the subjects are informed. The performance in random spatial configurations (type V) is not affected by numerical order. This indicates a fundamentally different type of scanning strategy probably based on the clarity of elements, and accordingly, dependent on the target distance to the point of fixation.

The next step in the analysis of display types was to separate the contribution of different spatial factors critical to search performance (i.e. the frequency of correct yes-responses). Thus, a number of multiple regression analyses were conducted; one for each combination of display type, numerical order and information condition. The following sets of factors were entered hierarchically into the regression equations: A - angular distance of target to probe number. LR - left/right part of the display. UD - up/down part, LRxUD - an interaction factor formed by the product of LR and UD; in step two and three of the analysis further interaction terms (products) were entered: AxLR and AxUD and, finally, the third order interaction AxLRxUD.

The effect of the information condition is clear; the explained variance in the informed condition across display types and numerical orders was $p = .757$ but $p = .579$ in the uninformed condition. This increase may depend partly on training since the informed

condition followed after the uninformed condition. There was no main difference between the systematic and random numerical orders ($p = .671$ and $p = .665$ across display types and information conditions). Contrary to the overall analysis of correct responses (see Figure 3) the effect of numerical order with respect to explained variance is evident only when related to display type and information condition.

The ranking of display types should be I (systematic spatial order) to V (random). In order to get a crude measure of the similarity of display types, the correlation between each pair of display types was computed with regard to the proportion of variance accounted for by each of the spatial factors included in the multiple regression analysis. Thus, the more similar two display types are, the more similar the pattern of explained variance accounted for by the spatial factors. The results of the correlational analysis is presented in Table 1.

Table 1. Correlations between display types with respect to explained variance accounted for by the spatial factors used in the multiple regression analysis. Data are from the uninformed condition with systematic numerical order.

	DISPLAY TYPES (Spatial order)			
	II	III	IV	V
I	.79	.74	.60	.02
II		.96	.81	-.37
III			.77	-.36
IV				-.25

The correlational pattern is in accordance with the predicted spatial order of display types with display type I as reference: Type I is most similar to type II; type II most similar to type III which is also rather similar to type IV. Type V is less dissimilar to type II, III and IV than to type I. The correlational pattern fits well with the rank order of display types obtained with magnitude estimations and reproduction in the experiment by Brännström (1980); the empirically obtained rank order of display types with regard to spatial redundancy of element positions was from type I to V across tasks.

The following rank order of display types was obtained with respect to the amount of explained variance in the multiple regression analysis: V (.78), I (.73), III (.64), II (.61) and IV (.60). This result means that the scanning strategies for the extreme display types I and V are most consistent with the experimental spatial factors. However, the most differentiated picture of the processing of display types is revealed when the explained variance is partitioned on the spatial factors included in the regression equation. Figure 4 shows the data from the condition where the stimuli are presented in a systematic numerical order for the uninformed group (left panel) and the informed group (right panel).

There is a conspicuous similarity in the pattern of explained variance for display types I-IV in the uninformed group (left panel); the LRxUD interaction factor is outstanding with respect to the amount of explained variance. The result accords with the suggestion that the subjects use the numerical size of the probe as a cue for directing the scanning. An independent correlational analysis showed that the scanning order which is most consistent with the result is a diagonal search, i.e. one where the upper left and the

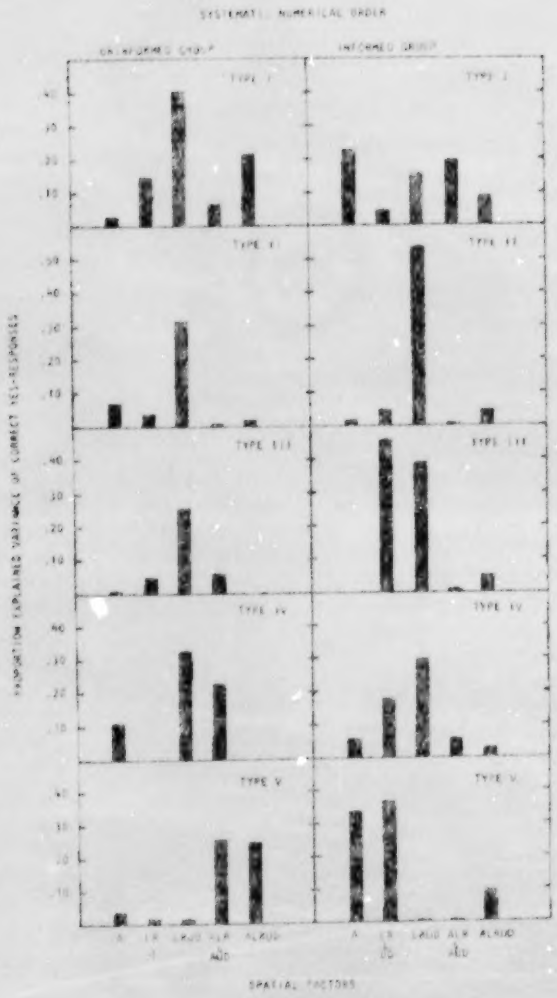

Figure 4. Explained variance partitioned on the spatial factors included in the regression equation for the uninformed (left panel) and the informed group (right panel) with systematic numerical order.

lower right parts of the spatial pattern of elements are given priority. The angular distance factor (A) and the LR and UD factors account for small amounts of explained variance. For the random display types (V) the effect of LRxUD is absent, while the effects of AxLR, AxUD and AxLRxUD are strong. These results are in accordance with the notion of a scanning strategy based primarily on element clarity which is probably realized by a "local search" and the utilization of end-segregated elements. End-effects are strong for the homogenous display type I, also.

When subjects are informed (right panel of Figure 4) there is evidence of a more consistent use of the numerical size of the probe as a cue for directing the scanning (across display types I-IV). The diagonal search is confirmed in this condition. For the random display types (V) the angular distance factor (A) now becomes very important while the LRxUD factor still explains a negligible amount of variance. Thus, a scanning according to element clarity is supported. Type I resembles type V with respect to variance accounted for by the A-factor and the AxLRxUD (end-effect) factor.

In Figure 5 the results from the condition with random numerical order are presented.

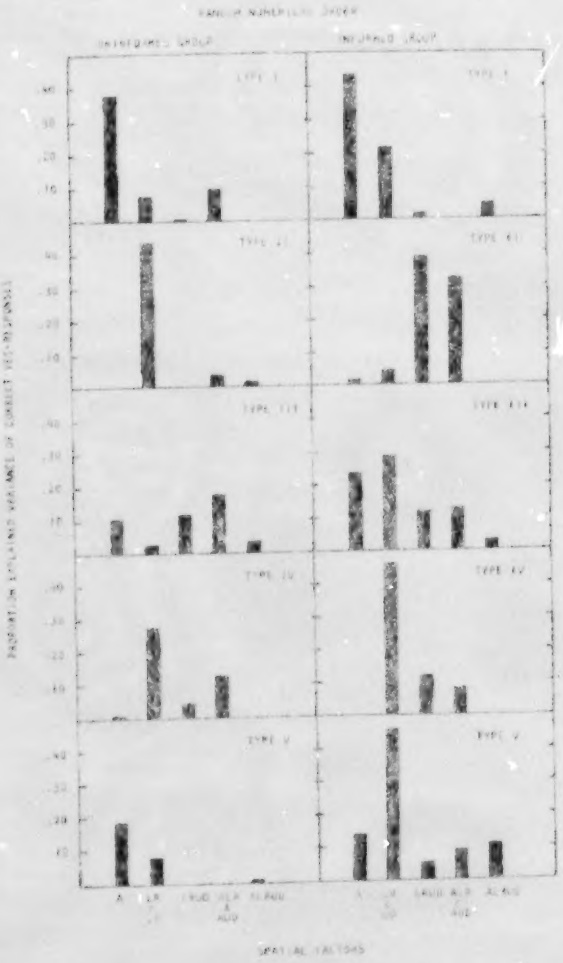

Figure 5. Explained variance partitioned on the spatial factors included in the regression equation for random numerical order. (Left panel - uninformed group; right panel - informed group).

Random numerical order has detrimental effects on the use of the numerical size of the probe as a cue for scanning the spatially systematic display types (I-IV), a fact revealed by the small amounts of variance accounted for by the LRxUD factor when subjects are uninformed (left panel). A more crude and less consistent scanning seems to occur which is reflected by the increased importance of the LR, UD, AxLR and AxUD factors. For the homogenous display type (I) the impact of element clarity (A) is very strong. For the random display types (V), the scanning seems to rely almost entirely on clarity of elements.

When subjects are informed about numerical order (right panel of Figure 5) the diagonal search is tried more consistently than in the uninformed condition; thus instruction about numerical order leads to a more consistent scanning behavior. However, the diagonal scanning should be inefficient and scanning behavior in turn becomes more variable; the increased role of the LR and UD factors together with the AxLR and AxUD factors lend support to such a description. For the random display types (V), factors including A account for considerable amounts of explained variance. Thus, the clarity of elements is important in scanning the random patterns of elements. Finally, the A-factor is outstanding for display type I which suggests that the homogenity of the spatial configuration can rule out the diagonal search in preference for element clarity.

Discussion

The results indicate that the subjects frequently based their scanning strategies on an expectation of a perfect correlation between the spatial and numerical orders of the stimuli. But post-experimental questioning of the uninformed subjects showed that none of them could report any awareness of a relation between spatial and numerical orders. Thus, the numerical stimulus material seems to have elicited well-learned cognitive operations, corresponding to reading habits for letter materials.

However, the spatial configuration of elements conditionally affects the way in which the numerical size of the probe is used as a cue to the spatial position of the target. When display types are spatially more systematic (types I-IV), an ordered search seems to occur while a search based on element clarity may take place when the displays are random configurations (V). The significant interaction effect between display type and numerical order which is more marked in the informed condition as compared to the uninformed condition, lends support to that interpretation. Thus, the numerical cue facilitates performance for display types I-IV when numerical order is systematic but has detrimental effects when the order is random. For the random spatial configurations (type V) subjects do not utilize numerical order as a cue in scanning. The observed dependencies between the spatial configuration of elements and their informational content confirm the results from Brännström (1980) regarding magnitude estimations of content attributes.

The more detailed analysis of the correct yes-responses by means of multiple regression analysis confirms the dependency between spatial configuration and numerical order. It was shown that the scanning order used in the more systematic display types (I-IV) best could be described as a diagonal scanning: When the numerical size of the probe number is small, the scan is directed to the upper left part of the display, but to the lower right part when it is large. This diagonal scanning was somewhat more pronounced when the subjects were informed about numerical order which suggest a more consistent search behavior due to instruction. When the spatial order was random (type V), diagonal scanning did not occur, and clarity of elements seems instead to have affected the scanning. This interpretation is supported by the impact of the angular distance factor (A) and interaction terms containing that factor. The effects of the third-order interaction factor (AxLRxUD) are especially interesting because they point to strong end-effects, probably because of less lateral interferences for the elements forming the boundaries of the spatial pattern.

The fact that the random display types (V) in general were processed more consistently than systematic display types strongly suggests that the numerical cue is used conditionally. For the systematic spatial configurations the cue is used consistently as if numerical order prevailed; this is an adequate strategy only when numerical order is systematic but not otherwise. For random configurations, the scanning may be consistently based upon the clarity of the stimulus elements.

This investigation was supported by a grant from the Swedish Council for Social Science Research.

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